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Final Technical Report
for
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"Data Reduction and Analysis of HELIOS Plasma Wave Data"

Submitted by:

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1.0 Title Page

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2.0 INTRODUCTION

This document is the Final Technical Report for the NASA Research Grant NAG 5-527, "Data Reduction and Analysis of the HELIOS Plasma Wave Data", awarded to the University of Iowa by Goddard Space Flight Center. The primary purpose of this grant was to allow for the continuation of the data reduction and analysis of the HELIOS plasma wave data from the University of Iowa HELIOS Solar Wind Plasma Wave Experiments [E5a] on HELIOS 1 and 2. Prior to June 1, 1985, the data reduction and analysis of the HELIOS plasma wave data had been supported under contract NAS5-11279 with Goddard Space Flight Center. That contract provided for the design, construction, testing, integration, and pre-launch activities of the University of Iowa HELIOS Solar Wind Plasma Wave Experiments instrumentation and the post-launch operations and data reduction and analysis activities. The objective of these experiments was the investigation of naturally occurring plasma instabilities and electrostatic and electromagnetic waves in the solar wind. To carry out this investigation, instrumentation consisting of a 16-channel spectrum analyzer connected to the electric field antennas, an antenna potential measurement system, a shock alarm system, and supporting electronics was designed, constructed, tested, and flown on the two HELIOS spacecraft.

HELIOS 1 was launched on December 10, 1974, and HELIOS 2 was launched on January 16, 1976. The University of Iowa HELIOS Solar Wind Plasma Wave Experiments operated perfectly throughout the entire life of the mission which lasted much longer than the planned 18 months originally expected. The useful life of HELIOS 2 lasted until March 21, 1980, when an automatic switching of the onboard power system killed the travelling wave tube amplifier and severely damaged the spacecraft's data handling subsystem. HELIOS 2 was finally commanded off on January 8, 1981. HELIOS 1 continued to operate until March of 1986 when its command receiver failed.

Many significant advances in the study of plasma waves in the solar wind have been made with data from the University of Iowa Plasma Wave Experiments on HELIOS 1 and 2. The first observations of intense electron plasma oscillations associated with Type III solar radio bursts were made with data from these instruments. These observations confirmed the basic electron plasma oscillation mechanism proposed by Ginzburg and Zheleznyakov in 1958 for the generation of the Type III solar radio emissions. A study of electron plasma oscillation events associated with Type III solar radio bursts, using data from HELIOS 1 and 2, IMP 6 and 8, and Voyager 1 and 2, found that these events showed a pronounced increase in both intensity and frequency of occurrence with decreasing heliocentric radial distance. Only the HELIOS spacecraft, with their close approaches to the sun (about 0.3 AU perihelion) have been able to provide in situ measurements of these events in the region of their highest occurrence.

The Type III solar radio burst itself has been studied extensively using data from the HELIOS spacecraft. Stereoscopic radio direction-finding measurements from the HELIOS 1 and 2, IMP 8, and Hawkeye 1 spacecraft were used to track a Type III solar radio burst in three dimensions, independent of modeling assumptions concerning the emission frequency as a function of radial distance from the Sun. By combining these radio direction-finding measurements with direct in situ measurements of the solar wind plasma density near the Sun, it was found that the dominant emission occurs at the second harmonic, $2f_p^-$, of the electron plasma frequency. The results of this study confirmed earlier results by other investigations which had to rely on assumed models for the radial dependence of the emission frequency or on average statistical properties of the solar wind.

Further work has also been done on the association of Type III solar radio bursts and electron plasma oscillations in order to provide important new information on nonlinear plasma processes of considerable current interest. A study of the volume emissivity of Type III solar radio bursts showed that although the emissivities varied over a large range, all the emissivities decreased rapidly with increasing heliocentric radial distance. The best fit power law for the events analyzed found the emissivity, J , proportional to $R^{-6.0 \pm 0.3}$. When the observed electron plasma oscillation intensities and variation with radial distance (E was proportional to $R^{-1.4 \pm 0.5}$) were used in two current models for the conversion of electrostatic plasma oscillations to electromagnetic radiation, the observed emissivities were shown to be in good agreement with the predicted emissivities.

The most commonly observed plasma wave detected by HELIOS is a sporadic emission between the electron and ion plasma frequencies. These waves are thought to be ion acoustic waves which are Doppler-shifted upwards in frequency from below the ion plasma frequency by the motion of the solar wind. Wavelength measurements from IMP 6 support this conclusion. Comparison of HELIOS results with measurements from this Earth-orbiting spacecraft show that the ion acoustic wave turbulence detected in interplanetary space has characteristics essentially identical to those bursts of electrostatic turbulence generated by protons streaming into the solar wind from the Earth's bow shock. In a few cases, ion acoustic wave enhancements have been observed in direct association with abrupt increases in the anisotropy of the solar wind electron distribution. Comparisons with the overall solar wind corotational structure show that the most intense ion acoustic waves usually occur in the low-velocity regions ahead of high-speed solar wind streams. Of the detailed plasma parameters investigated, the ion acoustic wave intensities are found to be most closely correlated with the electron-to-proton temperature ratio, T_e/T_p , and with the electron heat flux. Investigations of the the detailed electron and proton distribution functions also show that the ion acoustic waves usually occur in regions with highly non-Maxwellian distributions characteristic of double-proton streams. Two main mechanisms, an electron heat flux instability and a double-ion beam

instability, have been extensively studied as possible generation mechanisms for the ion-acoustic-like waves observed in the solar wind. More recently, the electrostatic lower hybrid instability has been studied as a possible generation mechanism when T_e/T_p is near one. The possible macroscopic consequences of the solar wind ion acoustic waves detected by HELIOS is uncertain. It has been suggested that ion acoustic waves in the solar wind could have important consequences for controlling heat conduction in the solar wind. However, the ion acoustic waves detected by HELIOS are usually very weak. The ratio of the electric field energy density to the plasma energy density, $E^2/8\pi nkT$, is only about 10^{-5} to 10^{-7} during intense bursts, and much smaller on the average. Whether such low intensities can have significant macroscopic effects on the solar wind still needs to be explored in more detail.

Plasma wave turbulence associated with interplanetary shocks has also been studied using the HELIOS plasma wave data. Three types of plasma waves are usually detected in association with a strong interplanetary shock: (1) electron plasma oscillations, (2) electrostatic ion-acoustic or Buneman mode turbulence from about 1 to 30 kHz, and (3) whistler-mode electromagnetic noise. The primary burst of electric and magnetic field noise at the shock occurs a few seconds after the jump in the magnetic field, with a broad maximum in the electric field intensities at a few kHz and a monotonically decreasing magnetic field spectrum below about 1 kHz. Many of the characteristics of strong interplanetary shocks are found to be closely similar to previous observations of plasma wave turbulence associated with the Earth's bow shock.

3.0 SUMMARY OF WORK ACCOMPLISHED

The major activity carried out under this research grant has been the continued reduction of the HELIOS Plasma Wave Experiment data into formats useful for continuing the research activities described above in the Introduction and below in the Future Research Activities sections. The University of Iowa Plasma Wave Experiments on HELIOS 1 and 2 operated satisfactorily for the entire lives of the HELIOS spacecraft and have provided us with much valuable data that has been and will continue to be important to space physics researchers. HELIOS 1 operated for an entire 11 year solar cycle and HELIOS 2 operated from about solar minimum until solar maximum. Under this research grant, we have continued the reduction of the data acquired from our experiments during the 11+ years of HELIOS 1 and 4+ years of HELIOS 2. We continued the production of 24-hour survey plots of our HELIOS 1 plasma wave data and submitted microfilm copies of them to the National Space Science Data Center. The 24-hour survey plot production for HELIOS 2 and submission of microfilm copies of that data to the National Science Data Center was completed under the previous contract. Much effort under this research grant involved the shock memory data from both HELIOS 1 and 2. This data had

to be deconvoluted and time ordered before it could be displayed and plotted in an organized form. Because of time correlation problems inherent in the way the raw shock memory data was acquired, extensive manual intervention in the reduction of the shock memory data was required. Thus we had a large backlog of HELIOS 1 and 2 shock memory data to process that had been acquired under the previous contract in addition to the newly acquired HELIOS 1 shock memory data. In support of current research efforts we also produced expanded time-scale plots for ourselves and for a number of colleagues including Professor H. Kikuchi (Nihon University and Max Planck Institut fur Aeronomie, Lindau), Professor F. M. Neubauer (University of Cologne), Drs. E. Marsch and A. Richter (Max Planck Institut fur Aeronomie, Lindau), and Dr. C. Dum (Max Planck Institut fur extraterrestrische Physik, Garching). During the period of this research grant, the UNIVAC 418-III computer we had been using was replaced by a DEC VAX 11/780 computer. In order to continue the reduction and analysis of the large HELIOS Plasma Wave Experiment data set that we had acquired, we had to rewrite all of our data reduction and analysis computer programs. Because of the limited funding available under this research grant (\$15,000), no extensive research project could be carried out. However, we were able to reduce and organize the data we had acquired into formats valuable for future research efforts such as those we will describe in the following section.

4.0 FUTURE RESEARCH ACTIVITIES

The HELIOS University of Iowa Plasma Wave Experiments data sets acquired during the 11+ years of HELIOS 1 and 4+ years of HELIOS 2 and processed under this research grant and the previous contract provide a valuable data set for continued space physics research. Several important research topics that could be pursued using these data sets if funding were available are described below.

Since HELIOS 1 operated for a full 11 year solar cycle, its data set provides the basis for a morphological study of plasma waves in the solar wind between 0.3 and 1.0 AU over a complete solar cycle. Correlative studies with the magnetic field, plasma, and energetic particle experiments' data sets should help identify the instabilities and processes occurring in the solar wind. As the HELIOS mission approached solar maximum, the number of solar radio bursts and interplanetary shock waves detected increased dramatically. This increase in activity provides many valuable opportunities for correlative studies with ISEE 1, 2, and 3 and IMP 8 to provide triangulation measurements of Type III solar radio bursts and other plasma wave events. Research efforts concentrating on the study of plasma waves associated with interplanetary shocks using a large number of events to investigate the dependence of the plasma wave intensities on the Mach number, magnetic field direction, shock normal angle, and shock source are important. Studies of electron plasma oscillations associated with Type III solar radio bursts and electron plasma oscillations and ion acoustic waves in the solar wind should also be continued.

5.0 TECHNICAL REPORTS

This final technical report is the only technical report submitted under this contract.

6.0 PUBLICATIONS

No publications were produced under this research grant.